Aspects of time variability of the surface solar irradiance as measured and analysed from ground-based measurements with a distinction of cloudiness

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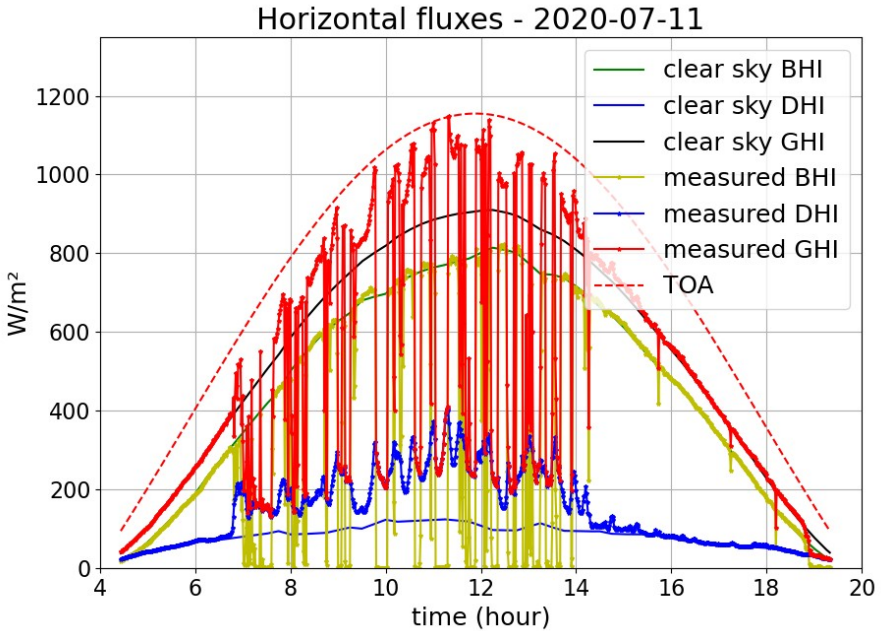
Thanks for the support of :

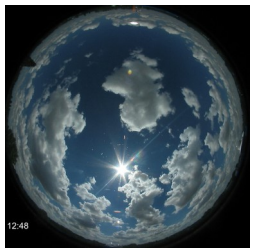
Objectives :
Describe and analyze the actual solar environment at the surface per sky situation, in particular for **fractional cloud cover**
These situations are complex because the sun is alternately hidden by, or between, clouds, creating very strong variation of Surface Solar Irradiance (SSI) (amount, partition direct/diffuse)
When the situation is of Clear Sun With Cloud (CSWC), irradiance enhancement (IE) may happen, and the **cloud radiative effect is positive**. Does it happen often ? Is it energetically important ? **Is it to be neglected, does it matter** ? How to analyze it ?

Motivations :
While SSI is important for surface energy budget and surface related processes (convection, solar energy conversion (photosynthesis, solar industry)), positive cloud radiative effect are rarely accounted for in forward or inverse radiative transfer modelling, or in budget calculation

Approach :
Exploitation of a long database of ground-based measurements at a given site, with distinction of situations, and use of RT modelling

Varying solar environment during a Cumulus day : illustration





Outline :

Description of facilities (ATOLL platform, and RT code)

Distinction between sun conditions

Monthly mean solar irradiance per sun condition, focus on CSWC conditions

Distinction between cloudy situations

Statistical description of the solar environment per cloud cover

Varying solar environment : description and effect at the daily scale

Statistics about cloud radiative effect over 2010-2016

Conclusions

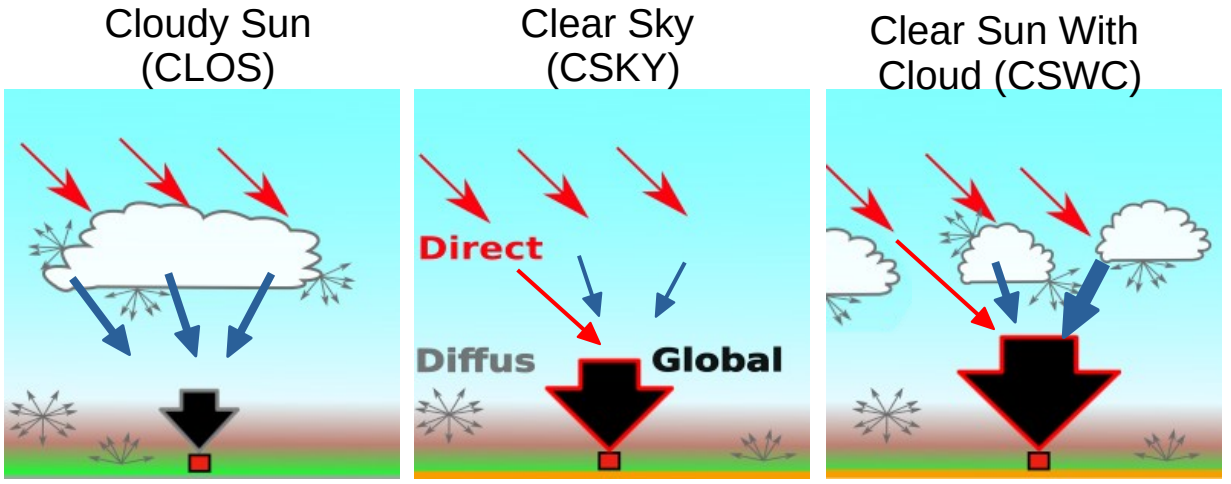
Description of facilities : ATOLL platform (ATmospheric Observations in LiLle)

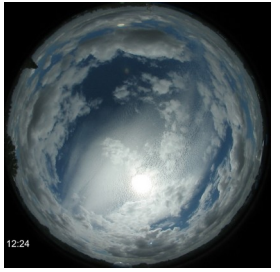
GHI : Global Horizontal Irradiance
BHI : Beam Horizontal Irradiance (from DNI)
DHI : Diffuse Horizontal Irradance

+Radiative transfer modelling : simulation of aerosol free (pristine) and cloud free SSI : LOA's code ARTDECO
→ calculation of radiative effects (RE)

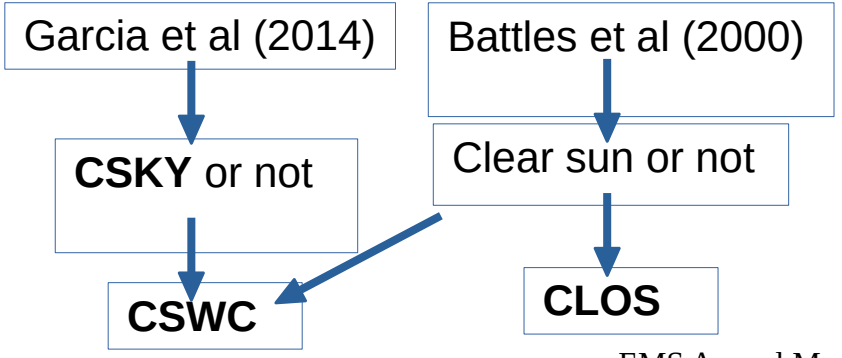
Instruments	measurements since	time step (min)	Information
Kipp & Zonen pyrheliometer + pyranometer with sun tracker and shading sphere	2009	1	DNI, BHI,DHI,GHI
Lidar mono or multi wavelength	2005	1	Cloud parameter : nlayer, base&top altitudes
CIMEL photometer (AERONET)	1994	15 then 5	aerosol properties
Skyimager (CMS Schreder)	2010	3	so far only qualitative

Distinction between sun conditions



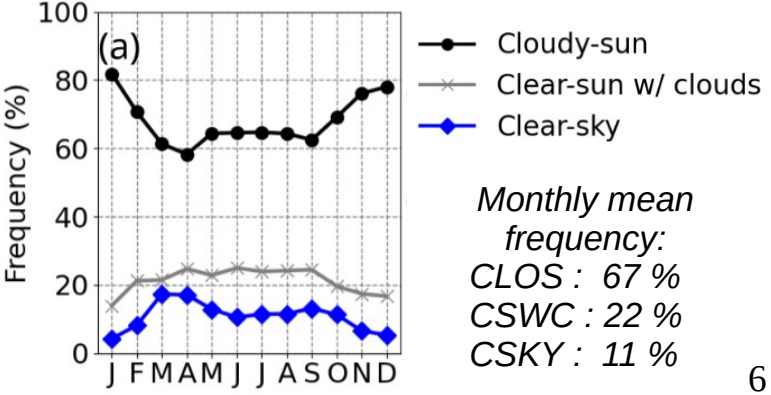


Applied filtering methods :



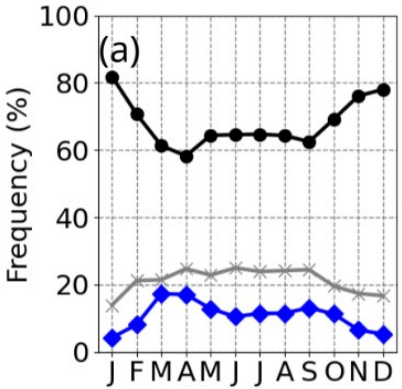
Chesnoiu et al (2024, ACP, accepted)

Results for Lille – 2010 → 2022



Monthly mean frequency:
CLOS : 67 %
CSWC : 22 %
CSKY : 11 %

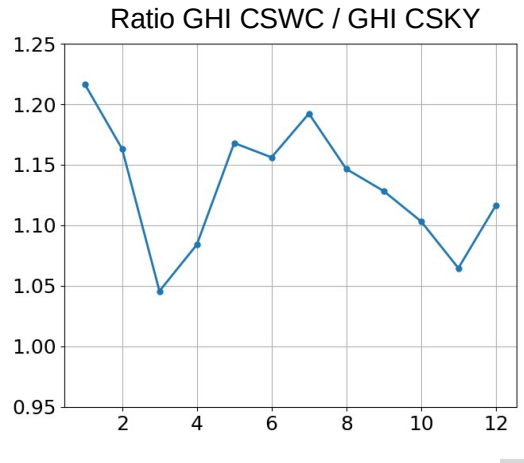
Monthly mean solar irradiance per sun condition

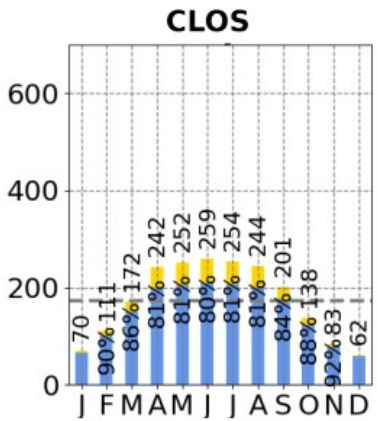


Cloudy-sun **(CLOS)**
Clear-sun w/ clouds **(CSWC)**
Clear-sky **(CSKY)**

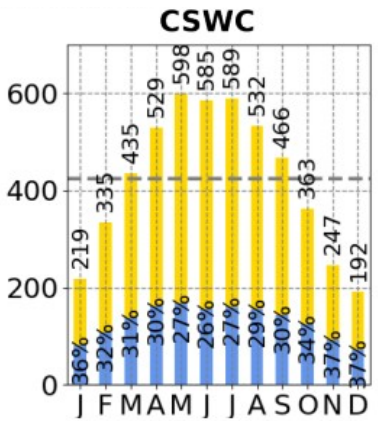
Direct
Diffuse
Mean GHI

Chesnoiu et al (2024, ACP, accepted)

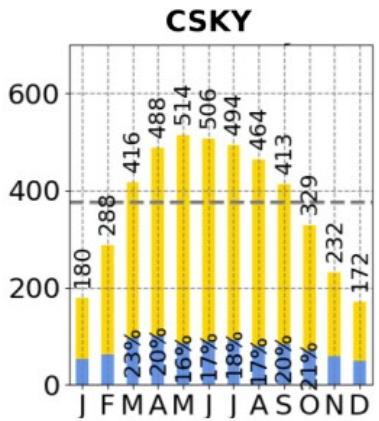




84% of diffuse



31% of diffuse



21% of diffuse

Focus on CSWC situations :

- maximum of GHI
- more diffuse than in clear sky
- actually $GHI_{CSWC} \simeq GHI_{pristine}$!

RE_{cloud} compensates $RE_{aerosol}$

Distinction between cloudy conditions

Strategy :

- Clear sky filtering
- Cloud type defined as in the ISCCP classification (type function of CTP, τ)
- Effective τ inverted from pyrheliometer measurements
- **Lidar** : cloud layer + cloud base and possibily cloud top altitudes
- **Temporal window** of ±30min around the measurement time :
  if 75% of a cloud-type identification : moment classified as Cumulus, Cirrus, .., moment.

Results for Lille 2010 -2016

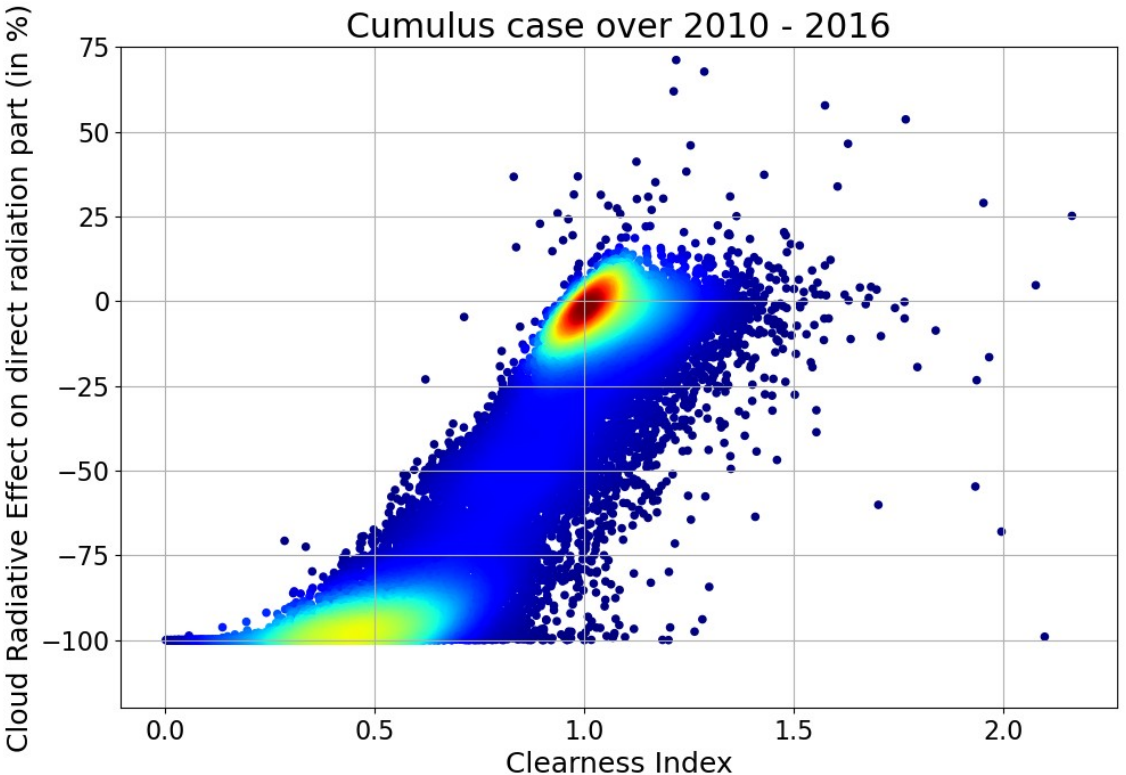
Sky type	Clear sky	Cumulus	Cirrus	Other	Cloud Mix	Isolated clouds	Thick clouds
Percent	12%	21%	15%	14 %	11%	13%	13%

	Cumulus	Cirrus
Clear sun with Cloud (CSWC)	34 %	53 %
Cloudy sun (CLOS)	66 %	47 %

→ Bimodal solar environment

Statistical description of the solar environment per cloud cover

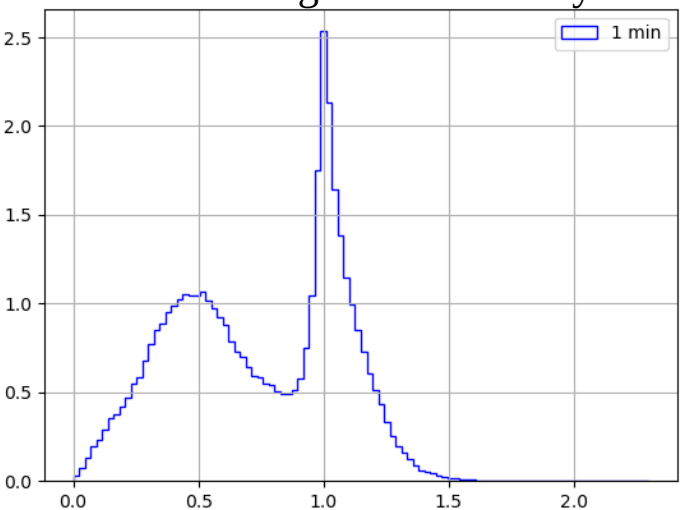
$$RE_{cloud} = F_{measur} - F_{cloud\ free}$$



Indeed a bimodal solar environment

GHI / GHI_{CS}=clear sky index (=K_c)

Normalized histogram of clear sky index



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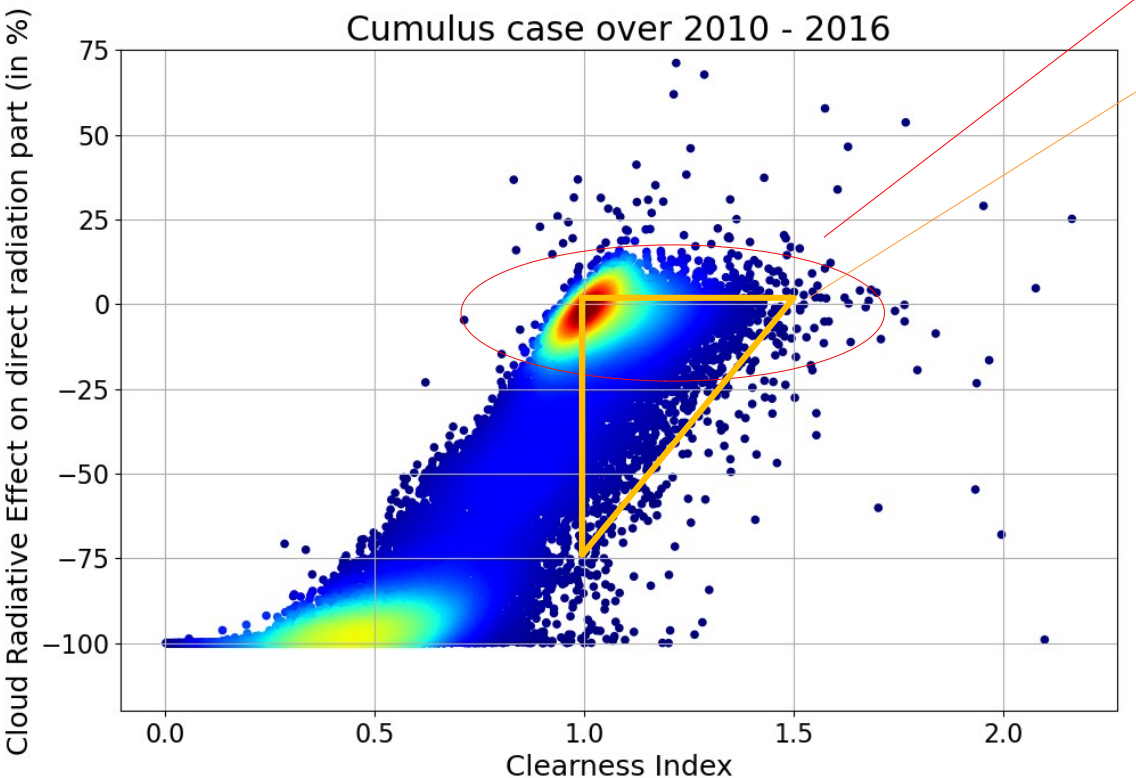


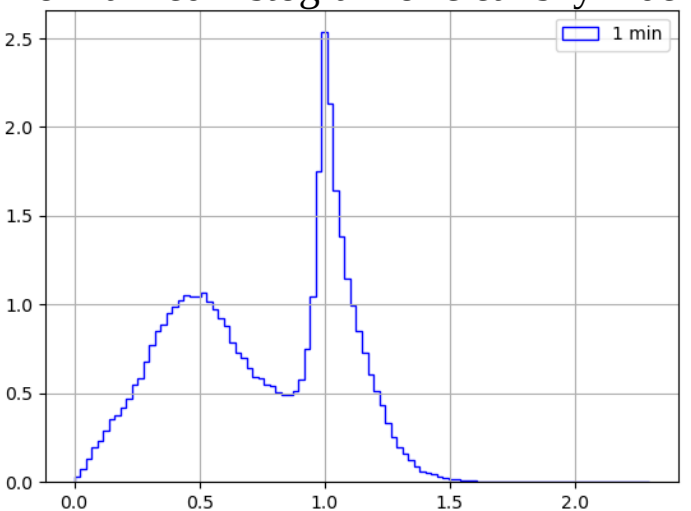
Indeed a bimodal solar environment

CSWC moments

$GHI > GHI_{CS}$

GHI / GHI_{CS}=clear sky index ($=K_c$)

Normalized histogram of clear sky index



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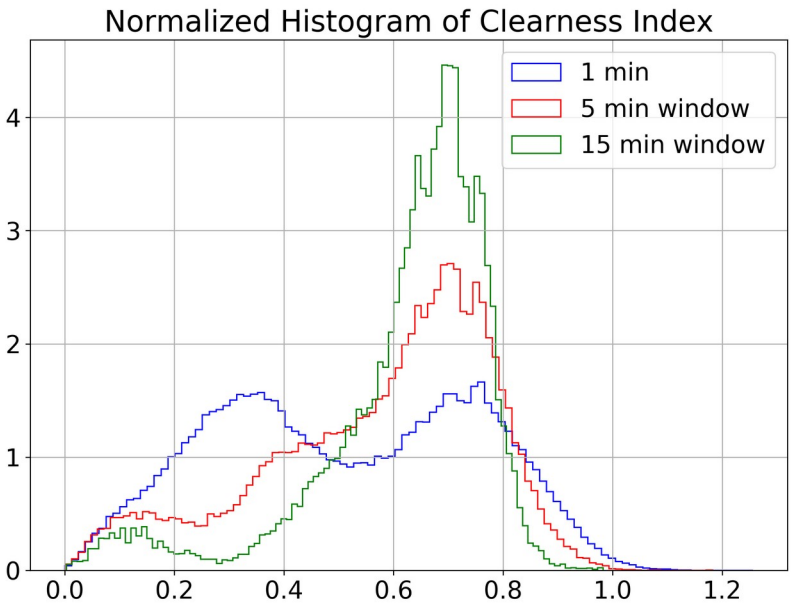
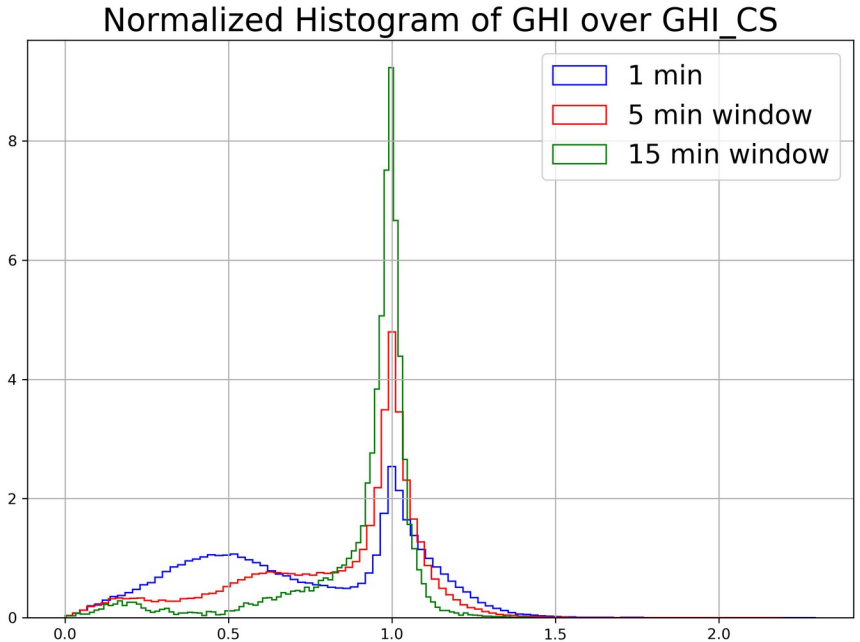


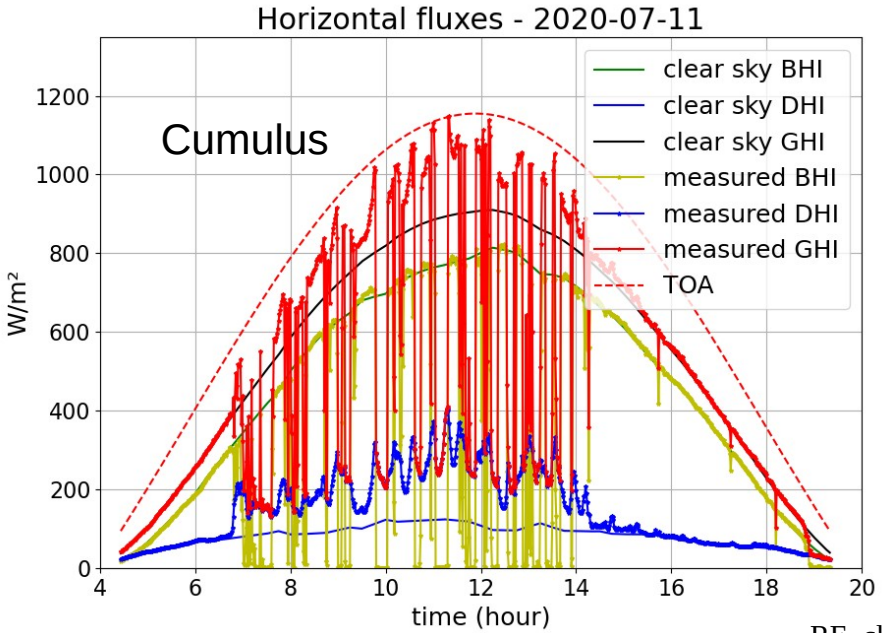
GHI / GHI_{TOA} =clearness index



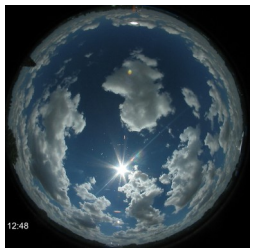
GHI / GHI_{CS}=clear sky index (=K_c)

Indeed a bimodal solar environment, that smooth with time window convolution → effect vanishes ?

Varying solar environment : description and effect at the daily scale

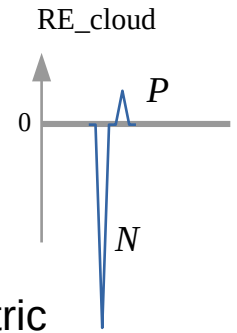


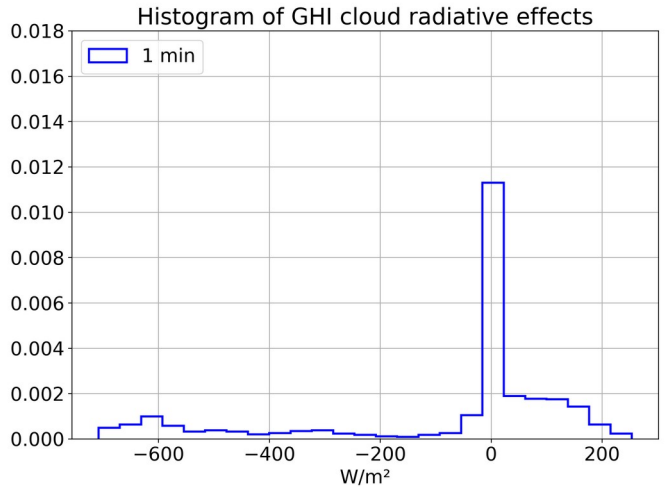
Sum of positive cloud effects =	+512.4	Wh
Sum of negative cloud effects =	-1623.9	Wh
Net radiative effect over the day =	-1111.4	Wh
Total energy received over the day =	7222.7	Wh
Clear sky energy of the day =	8334.1	Wh



	1 min
N/P =	3.2

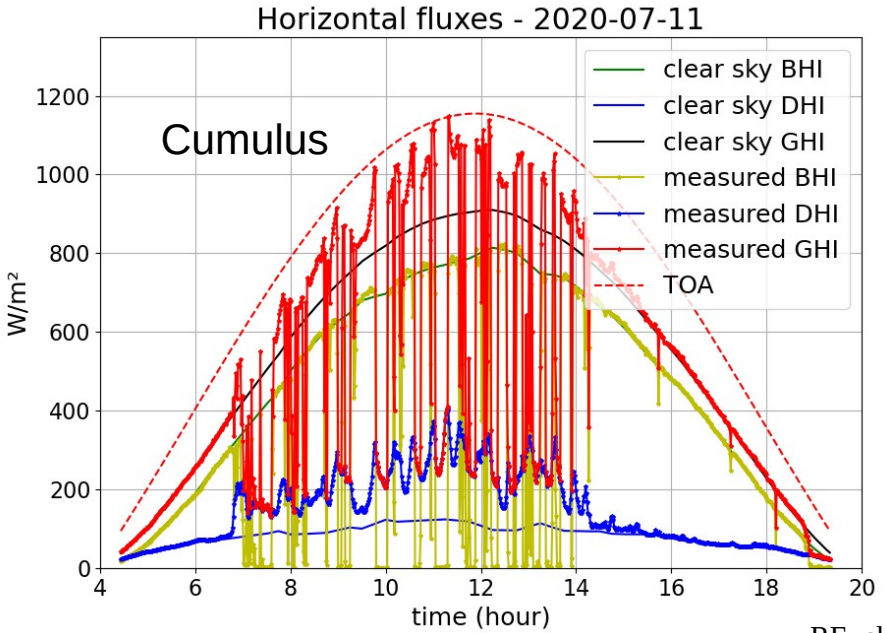
Proposition of a metric





Negative but also Positive Cloud Radiative Effects,

Varying solar environment : description and effect at the daily scale



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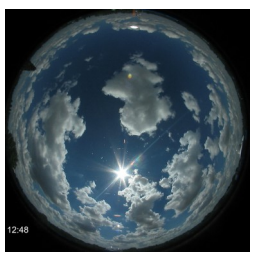
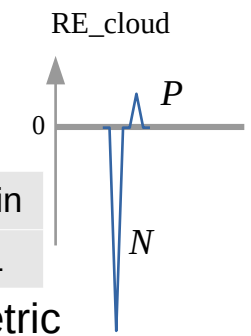
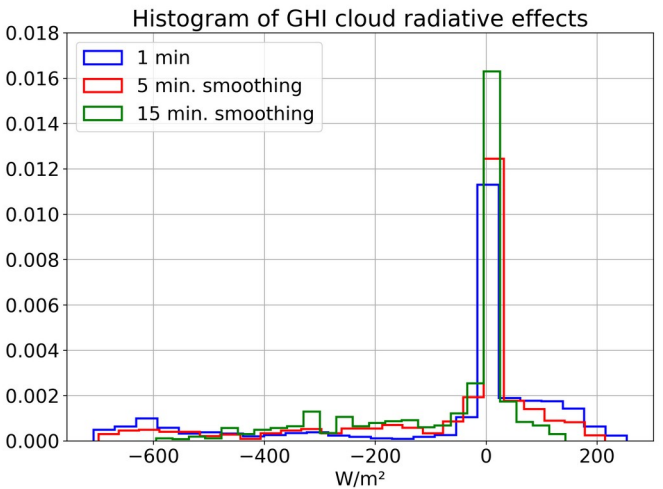


	1 min	15 min
N/P =	3.2	10.1

Proposition of a metric





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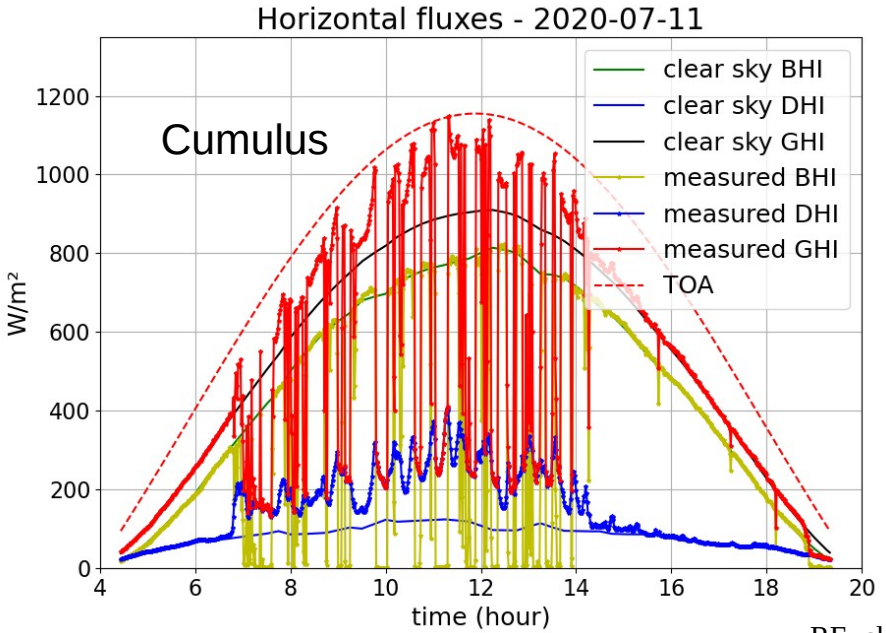

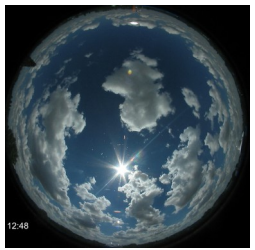

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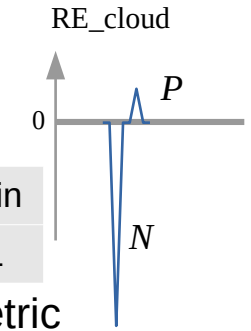
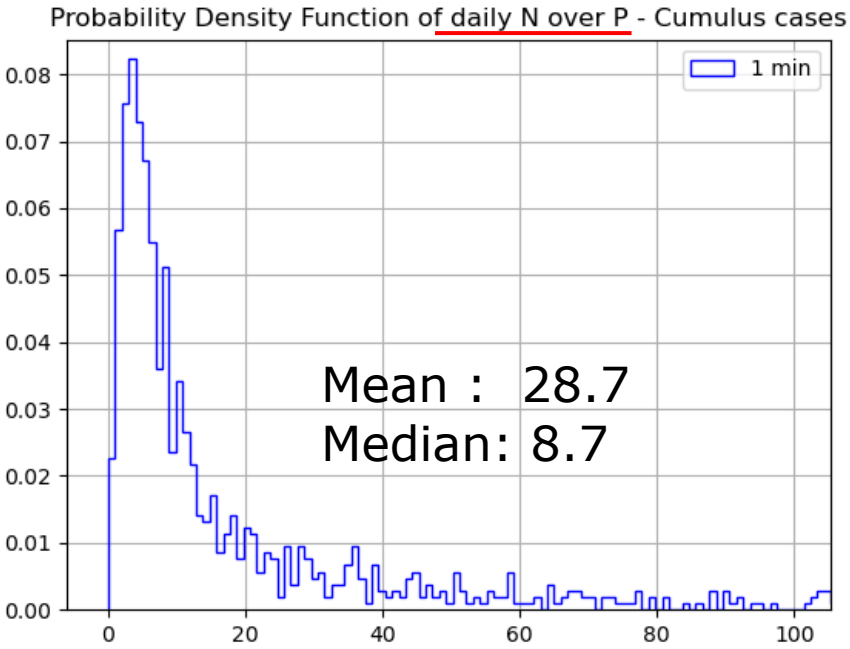


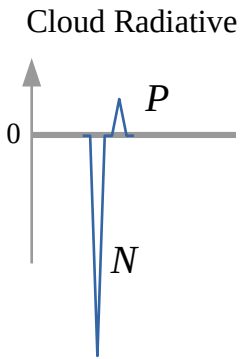
Over 2010-2016



Ways to assimilate these statistics ?

Statistics about cloud radiative effect over 2010-2016

Case Cumulus



- Not in brackets : cumulated in % over the Period

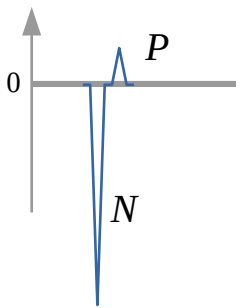
- In brackets : Mean % when observed

Case	CRE on	1 min	15 min window
All Negative and positive distinction	GHI	**-24.5%** (-25.9) -24.5% =-27.9%+3.3% *N/P* = 8.5	-**8.4%** (-9.5) -8.4% =-9.6%+1.2% *N/P* = 10.8
	BHI	**-53.9%** (-56.8)	**-21.3%** (-22.7)
	DifHI	**+85.2%** (+86.1)	**+34.4%** (+35.8)
When positive GHI CRE	GHI	20.2% of the time +13.8% (+15.4)	8.9% of the time +7.6% (+8.9)
	BHI	-6.3% (-6.6)	-5.2% (-5.1)
	DifHI	+106.4% (+99.7)	+65.2% (+56.5)
When negative GHI CRE	GHI	61.1% of the time -47.9% (-47.5)	38.9% of the time -21.7% (-25.8)
	BHI	-84.1% (-86.1)	-43.9% (-49.5)
	DifHI	+96.7% (+96.7)	+55.0% (+58.3)
When null GHI CRE	GHI	18.8% of the time 0.1% (-0.0)	52.2% of the time -0.4% (-0.5)
	BHI	-8.8% (-11.6)	-4.7% (-5.7)
	DifHI	+28.3% (+30.1)	+13.1% (+14.1)

Statistics about cloud radiative effect over 2010-2016

Case Cumulus

Cloud Radiative Effect (CRE)



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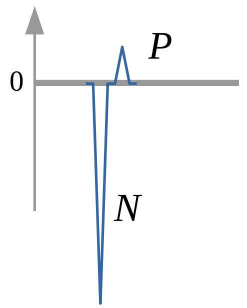
Reading :

At 1 minute scale :
- 20 % of the time : positive Cloud Radiative Effect
- on average :
  - 15 % more global energy than in clear sky
  - 100 % more diffuse energy

Statistics about cloud radiative effect over 2010-2016

Case Cumulus

Cloud Radiative Effect (CRE)



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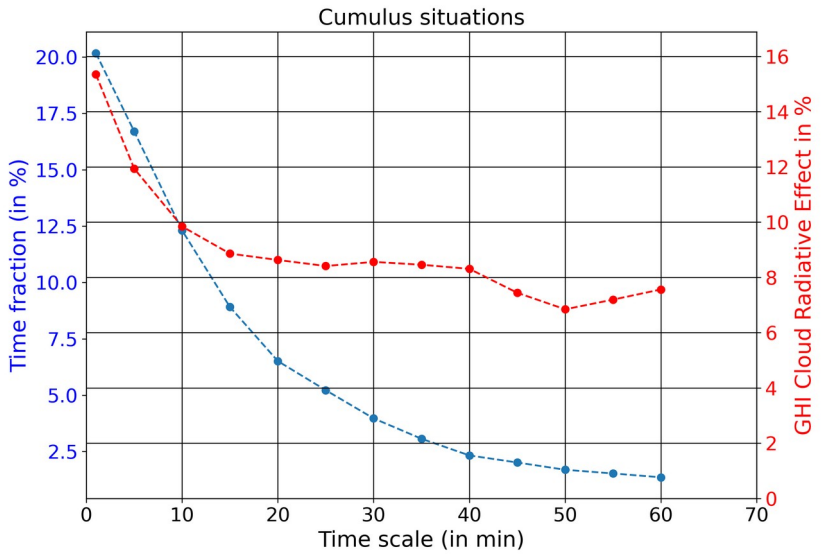
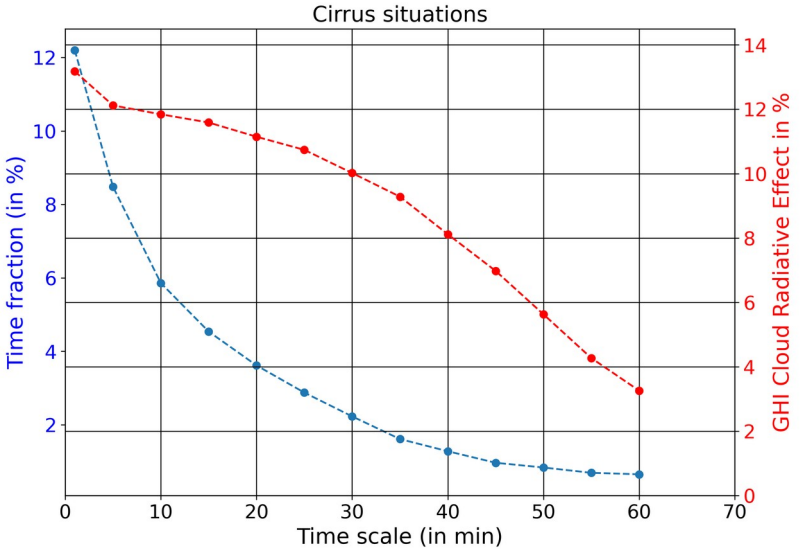
Positive CRE :

At the very large scale, positive CRE reduce the overal negative CRE by ~12 % Independently of the two time scales 1 and 15 minute.

Statistics about positive cloud radiative effects - variation with time average





→ Positive CRE are stronger in the case of Cumulus but decrease faster with time at scales below 15 minutes, compared with Cirrus

Conclusions :

From the exploitation of a database of ground based-measurements :

- CSWC situations are numerous and show irradiance enhancement that are significative

- CSWC situations : GHI is at the pristine level

- Compensation between the alternance of positive and negative cloud radiative effects with time window ; effects don’t vanish that fast ; not negligible at large scale (12%).

- These approach can be performed at other sites

- Rooms for paramerisation of these effects ; we are open for collaborations

- Questions :
  what is important for the study of surface-related processes ? For solar energy ?
  how to unbiased estimators, if possible, and inject statistics ?

Future works :

pursue the analysis, incorporate information from skyimager and thus cloud fraction

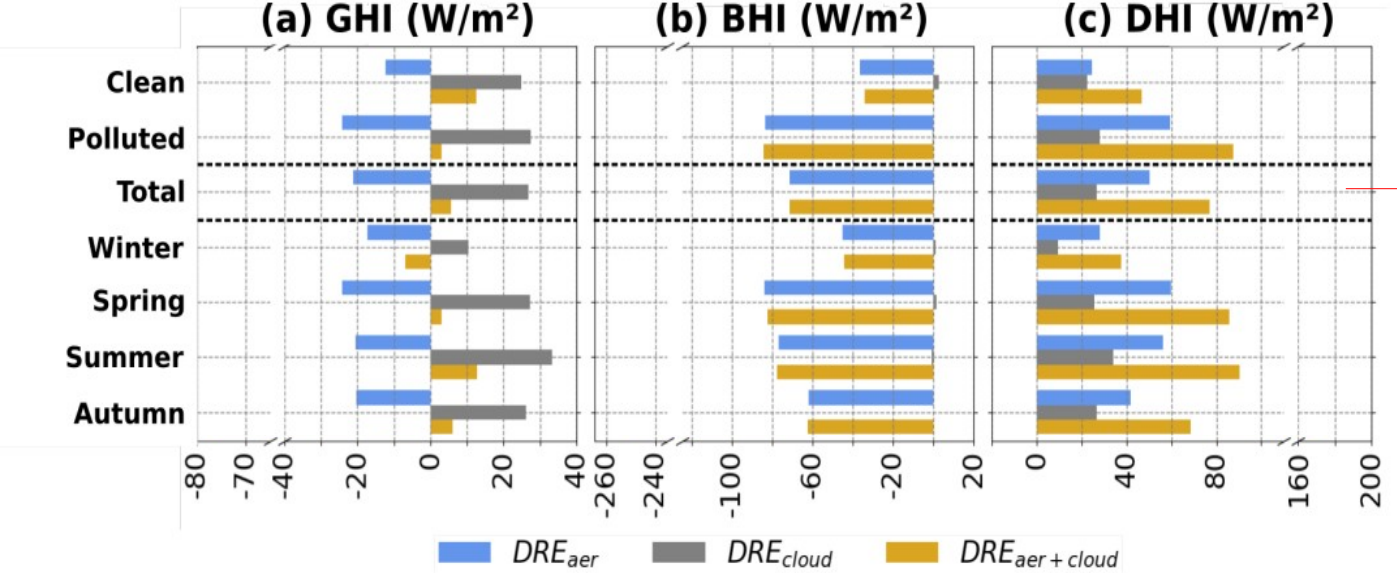
Keep focusing on the solar environment in CSWC situations :

Radiative Effect (DRE) of aerosol and clouds

$$DRE_{all} = F_{measur} - F_{pristine} = F_{measur} - F_{cloud\ free} + F_{cloud\ free} - F_{pristine}$$

$$DRE_{all} = DRE_{cloud} + DRE_{aerosol}$$

Chesnoiu et al (2024, ACP, accepted)



Example of DRE (in W/m²)

	DRE_{GHI}	DRE_{BHI}	DRE_{DHI}
aerosol	-20	-75	+55
cloud	+25	0	+25
total	+5		

GHI_{CSWC} (ie 22 % of the time) :
- **on average at the pristine level** !
- +164 % of diffuse c/w pristine (proportion from 10 to 25%)

Cloud free simulation

Precision reached with SOLARTDECO

LOA - input : AERONET level2.0